Recent Investments by NASA's National Force Measurement Technology Capability

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The National Force Measurement Technology Capability (NFMTC) is a nationwide partnership established in 2008 and sponsored by NASA's Aeronautics Evaluation and Test Capabilities (AETC) project to maintain and further develop force measurement capabilities. The NFMTC focuses on force measurement in wind tunnels and provides operational support in addition to conducting balance research. Based on force measurement capability challenges, strategic investments into research tasks are designed to meet the experimental requirements of current and future aerospace research programs and projects. This paper highlights recent and force measurement investments into several areas including recapitalizing the strain-gage balance inventory, developing balance best practices, improving calibration and facility capabilities, and researching potential technologies to advance balance capabilities.

I. Introduction

NASA's Aeronautics Evaluation and Test Capabilities (AETC) project was established in 2015 as the successor to the Aeronautics Test Program (ATP). AETC is responsible for the strategic direction of the portfolio of ground-test aeronautics capabilities at NASA's Ames Research Center (ARC) in Moffett Field, California, Glenn Research Center (GRC) in Cleveland, Ohio, and Langley Research Center (LaRC) in Hampton, Virginia. Through targeted investments, AETC provides the necessary research facilities and testing capabilities to support increasingly complex research and development programs and projects. AETC is organized into subprojects, each with unique objectives in support AETC's mission. The four subprojects are Test Technology, Capability Advancement, Operations, and Maintenance.

The Test Technology Subproject invests in specialized measurement sciences that provide support for ground testing. Disciplines included in Test Technology's portfolio are pressure, temperature, angle, force, and flow measurement. In additional to operational support, each test technology is responsible for advancing the measurement state-of-the-art to meet projected future needs of the experimental aeronautics community. Investments in each test technology are based on capability challenges, which define a high-level need or goal linked to NASA's aeronautics research challenges. Research tasks are proposed and executed to help meet the capability challenge(s).

Beginning in October 2016, AETC will begin supporting a new business model on behalf of NASA's wind tunnels within the project's portfolio that places a greater emphasis internal fundamental research by reducing the costs associated with ground testing to NASA researchers. As a result, usage of AETC facilities is expected to increase. By October 2018, most expenses for NASA researchers will be covered under the new operating model. However, items such as fabrication of test articles and use of test technologies will remain the financial responsibility of the project or program. Test Technology investments in measurement sciences will continue to be made based on current and new capability challenges.

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II. National Force Measurement Technology Capability

NASA's National Force Measurement Technology Capability (NFMTC), within the Test Technologies Subproject, maintains subject matter expertise in force and strain measurements. The NFMTC focuses primarily on force measurements made in wind tunnels (ex. balances), but subject matter expertise has been employed in other ground, flight, and space applications. Officially started in 2008, the NFMTC was established to rebuild and advance force measurement capabilities.[1] A decline in experimental programs within the aeronautics community and inconsistent funding resulted in an erosion of NASA's force measurement technical knowledge, infrastructure, and systems. Since its inception, the NFMTC has recaptured critical core force measurement knowledge and skills and made investments in infrastructure, systems, and staff to maintain and advance this critical discipline.

At its inception, a charter was established which defined the primary objectives of the NFMTC. These objectives were identified as enablers to increase critical skilled knowledge, advance technologies in new and existing balances and related systems, and demonstrate integrated system performance when using newly-developed technologies. The nine (9) primary objectives of the NFMTC are:

1. Recapitalize NASA strain-gage balance inventory
2. Develop a best practices for NASA strain-gage balance technology
3. Improve balance calibration capabilities
4. Establish and maintain staffing to sustain capabilities
5. Reduce task and contract 'turn-on' time
6. Increase research and development investments
7. Collaborate with the United States Department of Defense (DoD)
8. Collaborate with industry and academic partners
9. Be recognized as the force measurement experts for NASA

As identified in the charter, collaboration is a key aspect to sustaining the national capability. Fig. (1) shows the major partners in the NFMTC. These partners currently include the four (4) NASA centers, two (2) DoD bases, and two (2) contractors distributed across the United States. In addition to those shown in Fig. (1), the NFMTC maintains collaborative relationships with professional societies (ex. AIAA), universities, and other industry partners, creating a diversified network for sustaining and advancing the force measurement discipline.

II.A. NFMTC Capability Challenge

Capability challenges are high-level, 3- to 5-year efforts designed to meet the requirements of current and future customers of AETC facilities. The current NFMTC capability challenge is:

Advance force measurement capability to meet current and future aerospace research challenges

The goal of this challenge is to maintain, strengthen, and advance core force measurement capabilities for AETC research and production facilities by conducting sustainment and research activities in collaboration with DoD, industry, and academic partners. Capability challenges are expected to have outcomes or deliverables which directly benefit AETC or users of AETC facilities. For the current NFMTC capability challenge, these deliverables include

- Dissemination of critical force measurement knowledge and skills
- Increase in collaboration among other United States Government centers, industry, and academia
- Expansion of design capabilities for non-standard testing
- Development of force measurement best practices

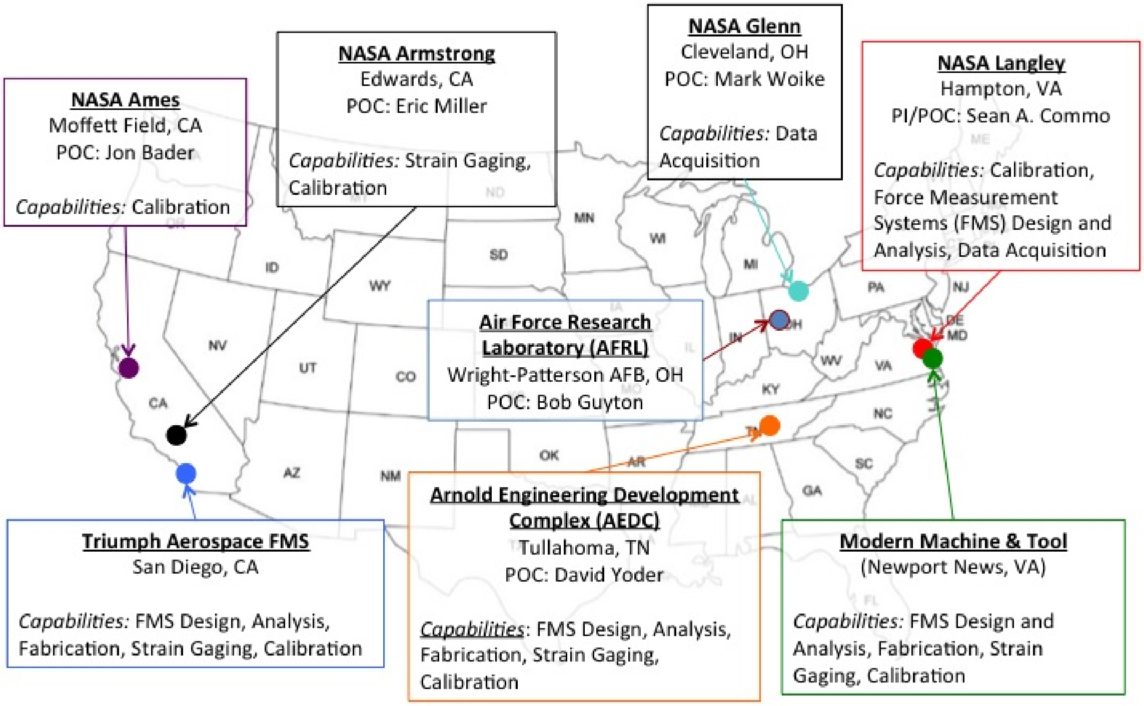

Figure 1. NFMTC Partners and Collaborators

- Increase in operational effectiveness and readiness
- Improvement in operational knowledge

In the following section, some current or recently completed investments into research tasks which support these stated deliverables are highlighted.

III. Current and Recently Completed Investments

III.A. Balance Calibration Laboratory Data Acquisition System Upgrade

The NASA LaRC Balance Calibration Laboratory includes the capability to perform long-arm and single-vector calibrations.[2] In 2015, an effort was funded to update the previous generation of data acquisition systems (DASs) in the calibration laboratory, which had been in service for over 20 years. Age and lack of available replacement hardware for failing components reduced the number of working DASs in the laboratory. The development of new DAS was also seen as an opportunity to establish a consistent platform by which future systems could be deployed across other NASA centers.

The new DAS were developed around the National Instruments™ PXI hardware platform.[a] This design was selected based on the integration of the hardware and software into a single unit. The meters, power supplies, and computer components were assembled into a system configuration in the previous generation of DASs. Additionally, the new systems maintained the measurement resolution of 7.5 digits over similar low-voltage measurement ranges of the previous generation systems. Three (3) identical systems, as shown in Fig. (2) were built with the following configuration:

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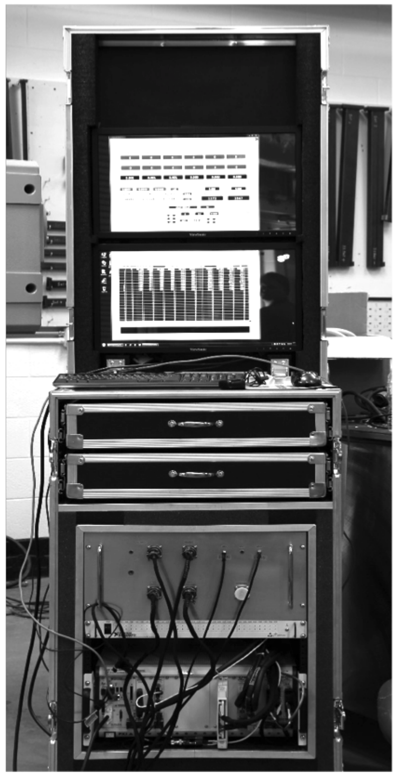

Figure 2. Next Generation Force Measurement Laboratory DAS

- 18-slot chassis
- Controller (CPU)
- Two (2) precision power supply modules
- Low-voltage multiplexer
- 7.5-digit digital multimeter module and 1000 V digitizer
- 24-bit thermocouple module
- 24-bit RTD module

This configuration permits acquisition of twelve (12) balance bridges, thirty-two (32) balance thermocouples and twenty (20) platinum resistive temperature (PRT) sensors, three (3) angle measurement systems, and laboratory environmental sensors by a single unit. Furthermore, the acquisition hardware, displays, and electrical connectors were integrated into a compact case for transportation. Customized data acquisition programs were developed to conduct long-arm calibration or single-vector calibration.

III.B. In Situ Load System Technology Demonstration

The In Situ Load System (ILS) was developed at the NASA LaRC to provide the ground-testing community a unique capability for performing balance check-loads that with future development may provide the ability for full or partial in-facility calibration.[3] The ILS was designed around the single-vector concept, which provides highly accurate, multi-component loads with a single force vector, used for balance calibration but with an emphasis on using the ILS in combination with the integrated, assembled model and balance system and the facility DAS to simulate the complete, as-tested research test-article system. For the researcher, the ILS provides a higher level of confidence in balance performance prior to beginning a wind-tunnel test.

To date, demonstration of the new capabilities of the ILS have been limited to use on a calibration fixture block.

Technology demonstrations are currently underway for two wind-tunnel entries: a powered, rotary-wing model in the NASA LaRC 14x22-Foot Subsonic Wind Tunnel and a fixed-wing, generic commercial transport model in the NASA ARC 11-Foot Transonic Wind Tunnel. Each demonstration is an opportunity to inform customers and facilities of the new capability as well as collect feedback on potential system improvements and develop procedures for system integration into standard operations at AETC facilities. Fig. (3) shows

Figure 3. Conceptual Use of ILS on Fixed-Wing Commercial Transport Model

the conceptual integration of the ILS with a fixed-wing commercial transport model inside a wind-tunnel test section.

The powered, rotary-wing model, shown in Fig. (4), is mechanically-complex model with multiple parasitic load paths caused by:

- powered rotor supply lines
- high pressure air lines
- instrumentation and control lines

Two balances are installed inside the model for the necessary force measurement capabilities. The fuselage balance is used for obtaining information on the aerodynamic performance of the vehicle. A second, non-

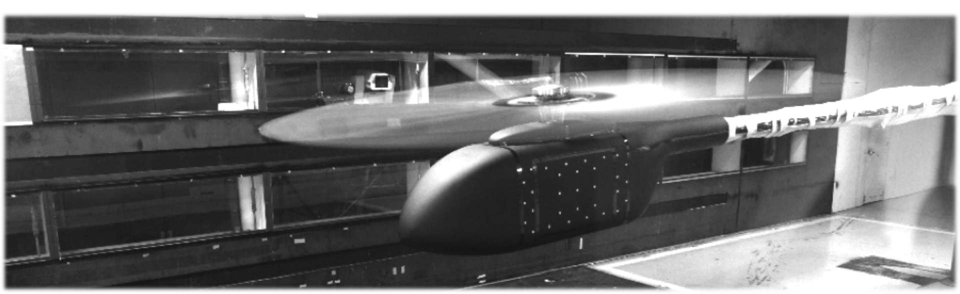

Figure 4. Powered, Rotary-Wing Model

rotating balance provides measurement of the torque of the rotorcraft powertrain. The ILS is being used

to apply check-loads to the rotor balances, which will mark the first time that system-level check-loads are performed. Check-loads of the rotor balance will be performed without the model body. An interface plate is used to mount the ILS to the transmission cover. The model is in a standard, upright position, which inverts the ILS in the direction opposite to gravity. For the demonstration, the model assembly will be rotated 180 degrees so that the load applied by the ILS re-aligns with gravity as designed.

III.C. On-Board Electronics and Wireless Telemetry Development for Rotating Balances

Starting in 2008, engineers at NASA GRC began developing on-board electronics and a wireless telemetry systems, as shown in Fig. (5) to simplify data acquisition from rotating balances used in fan models. The new

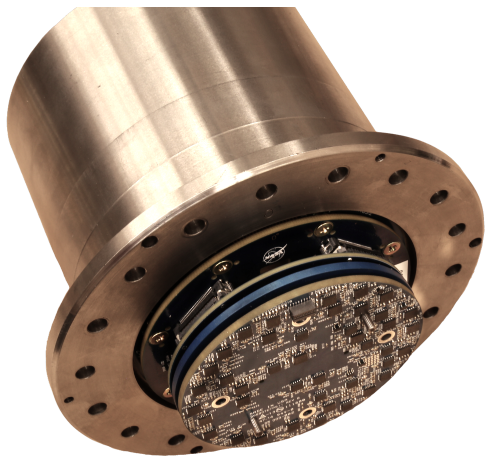

Figure 5. On-board Electronics and Wireless Telemetry on Rotating Balance

ultra-high bypass (UHB) telemetry system accommodates up to twelve (12) balance bridges, twenty-four (24) strain gages, four (4) bridge-based pressure transducers, eight (8) resistive temperature detectors (RTDs), two (2) board temperatures, and seven (7) on-board voltage monitors. The system utilizes 24-bit analog-to-digital converters (ADCs) for balance bridges, strain gages, and pressure transducers, which provide the capability simultaneous sampling and synchronization amongst the integrated circuits. The remaining signals are sequentially sampled by a single ADC. The new system currently utilizes the legacy receiver rack with a new receiver card; the legacy analog output cards are still in use. The new system replaces the hard-wired logic in the onboard electronic package and receiver card with field programmable gate arrays (FPGAs). The onboard electronics package utilizes a military standard FPGA and the receiver card uses a standard commercial FPGA. The receiver card handles interfaces to host computers, IRIG, and driving the backplane interface to the analog output cards. The receiver also handles digital signal processing (DSP) filtering of the data for slower rate hosts and scaling of data according to calibration data. The onboard electronics package provides constant voltage excitation of 5.0 V for balance bridges and bridge based pressure transducers, constant current excitation selectable from 1.0 mA to 12.5 mA for strain gages, and 1 mA constant current for RTDs. The balance signal gain is user selectable for all channels. Sampling frequency is also controllable via FPGA configuration. Utilizing the bidirectional communication of the gigabit Ethernet link, gains and stain-gage current excitation settings can be changed remotely.

The digitized data is transferred out of the rotating model via one of two methods: a set of two magnetically coupled coils providing uni-direction serial links or a fiber-optic slip-ring providing gigabit Ethernet. An FPGA based receiver card is at the other end of either link. The receiver card drives a set of analog output cards via a backplane interface, serves digital data to data system clients via a TCP/IP interface, provides DSP filtering of raw data for slower clients, and provides correction of data according to calibration data.

III.D. Overview of Other NFMTC Investments

Additionally, other NFMTC activities and investments have been recently completed or are currently in-progress. These activities support both the current AETC capability challenge and the NFMTC charter, as well as fulfill the needs and requests of force measurement capabilities from the aeronautics research community. In 2014, an initiative was undertaken to create a repository of the balances owned by NASA, the DoD, other U.S. Government National Labs. This new tool, known as the National Balance Inventory website, was developed to aid balance engineers and researchers in selecting an existing balance given known force measurement test requirements. The website was commissioned in 2015 and the database is used to facilitate balance loans and technical support between NASA centers and the Department of Defense's Arnold Engineering Development Complex (AEDC) and Air Force Research Laboratory (AFRL).

The NFMTC maintains a lead role in the Internal Balance Technology Working Group (IBTWG) within the American Institute for Aeronautics and Astronautics (AIAA). The working group provides an international forum for discussing and developing force measurement best practices.[4] A revision to the *Calibration and Use of Internal Strain-Gage Balances with Application to Wind-Tunnel Testing* recommended practice document is in-progress and members of the NFMTC are leading teams within the working group in areas such as load schedule design, calibration matrix development, uncertainty estimation, and facility check-load recommendations. In collaboration with the IBTWG, the NFMTC seeks to improve the uniformity of data analysis and the integration of the calibration matrix with the wind tunnel by developing a software package for analyzing balance calibration data.

The NFMTC has recently developed a balance design training course to capture and archive over 60 years of force measurement experience within NASA. The training emphasizes NASA Langley-type, single-piece balances and will be used to mentor new balance engineers across NASA and DoD. Furthermore, the training course provides perspective and insight in potential areas of advanced balance design research. These areas include design, manufacturing, sensor technologies, materials, calibration, and data acquisition.[5]

IV. Long-Term Vision of the NFMTC

As one of the primary measurements for wind tunnels, the long-term vision for the NFMTC is to continue to build and enhance force measurement capabilities within NASA and increase collaboration with DoD and other partners. This includes continuing to invest in personnel in order to maintain and grow a stable core of force measurement subject matter expertise, establishing consistent best practices for force measurement across NASA and the DoD, and increasing awareness of the NFMTC. Since an increase in wind-tunnel research is expected under the new funding model for AETC facilities, refining new capability challenges that align with researcher needs of the aeronautics community to guide areas where research investments in force measurement technologies are needed.

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